A Study on Earthquake Response Considered Vibration Characteristics of Superstructure and Substructure of Seismically Isolated Buildings

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SUMMARY:
This paper investigates the seismic response of seismically isolated buildings with a vibration system above and/or below the isolation layer. We describe a method to replace a multi-mass model with a simplified three-mass structural model to evaluate the response simply. In addition, the mean square of the response of three-mass structural model is calculated by random vibration analysis, when the excitation is ideal white noise acceleration of the ground motion. And structural elements affecting the response amplification and the degree of response amplification are recognized. By a comprehensive summary of the condition to ensure the integrity of the isolated buildings, it is possible to evaluate a simplified seismic response of buildings and to increase the degree of freedom in ground conditions and elevation conditions.

Keywords: Seismic Isolation, Random Isolation Theory, Modal Coupling Effect, Frequency Response Function

1. INTRODUCTION

Seismically isolated (SI-) buildings have been increased since the Hyogo-ken Nanbu Earthquake (1995) in Japan. SI-buildings are effective in the case of the short period building constructed on a firm ground. However, recently the scope of application of SI-buildings is spread because of the difficulty in selecting the construction site and improvement of the seismically isolation technology. Therefore, SI-buildings with a vibration system above and/or below the isolation layer are constructed. For example mid-story isolated buildings, SI-buildings on the soft ground and high-rise SI-buildings are as shown in Fig.1.
However, there are limitations for SI-buildings around the world. In United States, a performance more than earthquake-resistant construction is required to the superstructure of SI-buildings. In China, when SI-buildings whose natural period of the superstructure is over 1 second are designed, the shaking table test is needed. Because of the above descriptions, SI-buildings in the other countries are not as popular as in Japan. In Japan, high-rise SI-buildings over 100m in height are constructed and SI-buildings constructed on the soft ground constitute 20% to 30% every year. In the SI-building on the soft ground, it is possible that the soil-structure interaction on the response is greater. Mid-story isolated buildings have attracted attention for adaptability to variable needs as urban development projects and seismic retrofit in Japan. It is clarified that in the mid-story isolated buildings, the response amplification of superstructures is caused by modal coupling effects between modes of vibration on the superstructure and substructure (Kobayashi.M et al. 2008). It is also clarified that the period ratio between the superstructure and the substructure has a significant impact on the equivalent damping ratio of mid-story isolated buildings, and higher mode response contributes significantly to the story shear force of the substructure (Shiang-Jung Wang et al. 2011). In this paper, the effect of relationship between the vibration characteristics of the superstructure and substructure to the building vibration is recognized. In addition, this paper describes a method to replace a multi-mass model with a simplified three-mass model. In addition, the mean square of the response of three-mass structural model is calculated by random vibration analysis. These methods enable to evaluate the response simply.

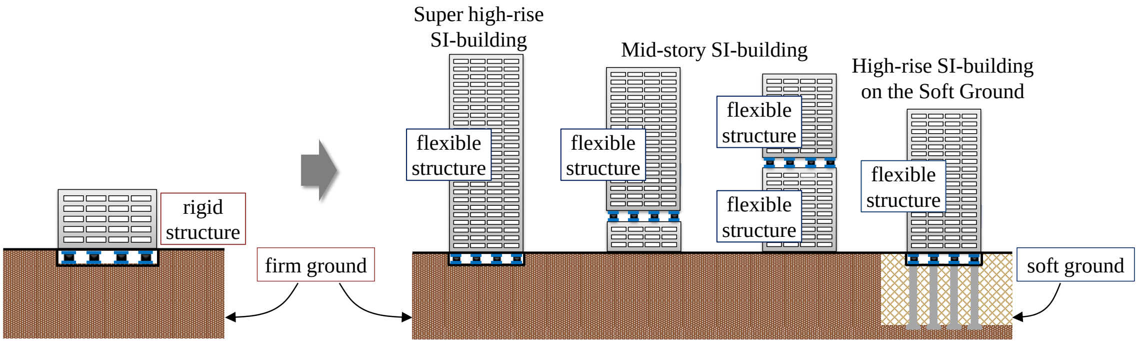

Figure 1. Expansion of the scope of application of seismic isolation building

2. ANALYTICAL MODEL AND ANALYSIS METHOD

2.1. Free-Free Mode of Vibration

Skinner revealed the contribution of higher mode to seismic response of SI-buildings by sweeping the model response with free-free mode of shape vectors (Skinner et al. 1993). The free-free mode of vibration is obtained when the stiffness of seismic isolation layer is zero. In this study, the same method is applied to the mode of a superstructure. The free-free mode shape vector $\mathbf{u_0}$ and natural circular frequency ω_0 are as follows:

$$\mathbf{K}_0\mathbf{u}_0 = \omega_0^2\mathbf{M}\mathbf{u}_0 \tag{2.1}$$

where $\mathbf{K}_0$ and $\mathbf{M}$ are the stiffness and mass matrix of structures, respectively, as stiffness of isolation layer is zero. The frequency equation of the superstructure is as follows:

$$\det\left|{}_u\mathbf{K}_0 - {}_u\omega_{FF}^2\,{}_u\mathbf{M}\right| = 0 \tag{2.2}$$

The ratio γ_1 between the ${}_2\omega_{FF.u}$ (as the second natural circular frequency of superstructures) and the ${}_1\omega_\ell$ (as the first natural circular frequency of substructures), and the ratio γ_2 between the ${}_2\omega_{FF.u}$ and the ${}_1\omega_F$ (as the first natural circular frequency of isolation layer) are defined in Eqn.2.3. The mass ratio μ between the m_{sup} (as total mass of the superstructure) and m_{sub} (as total mass of the substructure) is defined in Eqn.2.5. These values are the analytical parameter in this paper.

$$\gamma_1 = {}_2\omega_{FF,u}/{}_1\omega_\ell\,, \qquad \gamma_2 = {}_2\omega_{FF,u}/{}_1\omega_F \tag{2.3}$$

$$\mu = m_{sup}/m_{sub} \tag{2.4}$$

2.2. Analytical Model

Analytical model is three-mass model replaced from multi-mass model which simulates the actual structures as shown Fig 2.

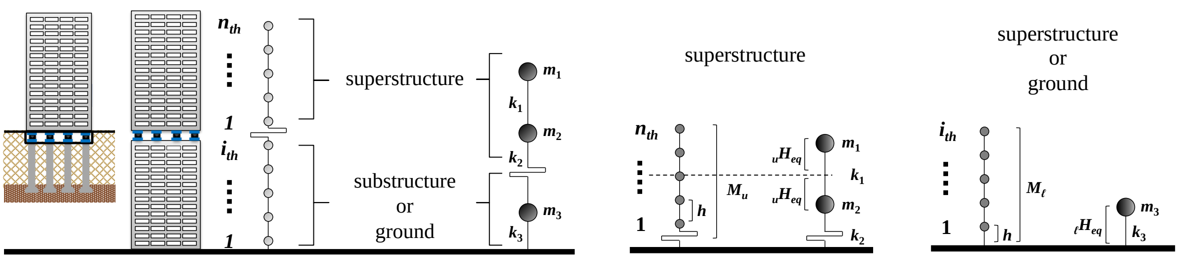

Figure 2. Replacement method to three-mass model

The mass of the superstructure and substructure can be expressed as follows:

$$m_3 = m_2 = M_u/2\,, \qquad m_1 = M_\ell \tag{2.5}$$

where *n* and *i* are the number of the superstructure and substructure of multi-mass model, respectively; *m* and *k* are the mass and stiffness of the superstructure and substructure of the three-mass model, respectively; M_u and M_ℓ are the total mass of the superstructure and substructure of multi-mass model, respectively. The natural circular frequency of the superstructure and substructure of three-mass model can be expressed as follows:

$${}_2\omega_1 = {}_2\omega_{FF,u}\,, \qquad \omega_2 = \omega_F\,, \qquad \omega_3 = \omega_\ell \tag{2.6}$$

$${}_2\omega_{FF,u} = \sqrt{k(m_1 + m_2)/m_1 m_2} \tag{2.7}$$

where ${}_2\omega_1$ and ${}_2\omega_{FF,u}$ are the second modal natural circular frequency of the superstructure of the multi-mass model calculated by Eqn.2.2, respectively; ω_2 and ω_3 are the natural circular frequency of the isolation layer and substructure of three-mass model, respectively; ω_F, and ω_ℓ are the natural circular frequency of the isolation layer and substructure of multi-mass model, respectively. The equivalent heights are given as follows:

$${}_u H_{eq} = \sqrt{\frac{(N+1)(N-1)}{12}}h\,, \qquad {}_\ell H_{eq} = \sqrt{\frac{(N+1)(2N-1)}{6}}h \tag{2.8}$$

where ${}_uH_{eq}$ and ${}_\ell H_{eq}$ are the equivalent height of the superstructure and substructure of the three-mass model, respectively. *h* is the story height of the multi-mass model. It enables to be simplified to evaluate the response.

3. EIGENVALUE ANALYSIS

3.1 Natural Frequency and Mode of Vibration

The eigenvalue problem of Eqn.3.1 is solved to obtain the *i*-th modal parameters.

$$\mathbf{A}\mathbf{u}_i = \lambda_i \mathbf{u}_i\,, \qquad \mathbf{A} = \begin{bmatrix} 0 & \mathbf{I} \\ -\mathbf{M}^{-1}\mathbf{K} & -\mathbf{M}^{-1}\mathbf{C} \end{bmatrix} \tag{3.1}$$

where **M**, **C**, **K** and **I** are mass, damping, stiffness and unit matrix, respectively; λ_i and $\mathbf{u}_i$ are complex eigenvalue and eigenvector, respectively. The *i*-th natural frequency f_i and damping ratio h_i are given by Eqn.3.2.

$$f_i = |\lambda_i|/2\pi\,, \qquad h_i = -\mathbf{Re}(\lambda_i)/|\lambda_i| \tag{3.2}$$

Fig.3 shows the modal participation function calculated by Eqn.3.2. At γ_1=0.9 and 1.5, the direction of the second and third modal participation functions of superstructure are opposite and the amplitude is almost equal. The relative story displacement of isolation layer is large in the second mode, and it is small in the third mode. At γ_1=1, the second and third modal participation functions of the superstructure become considerable amplitude and the relative story displacement of isolation layer is small in the second mode. At γ_1=1, the second modal damping ratio is 2.4%, because the damping ratio of the isolation story cannot be taken in the second mode. The third modal damping factor is 7.5%, because the damping ratio of the isolation layer can be taken in the third mode.

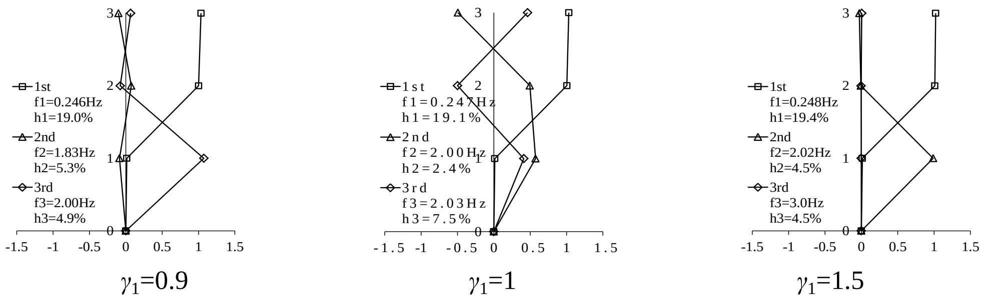

Figure 3. Modal participation function

3.1. Frequency Response Function

As sinusoidal excitation $\ddot{x}_0 = e^{i\omega t}$ interacts to the system, the $H_{y,j}(i\omega)$ as frequency response function of *j*-th story displacement is evaluated as follows:

$$\mathbf{H}_y(i\omega) = -\left(-\omega^2\mathbf{M} + i\omega\mathbf{C} + \mathbf{K}\right)^{-1}\mathbf{M}\{1\} \tag{3.3}$$

$$\mathbf{H}_y(i\omega) = \left[H_{y,1}(i\omega) \;\; H_{y,2}(i\omega) \;\; \cdots H_{y,j}(i\omega) \;\; \cdots \;\right]^T \tag{3.4}$$

The $H_{\ddot{x},j}(i\omega)$ as frequency response function of *j*-th story absolute acceleration and $H_{r,j}(i\omega)$ as that of *j*-th story relative story displacement are evaluated by $H_{y,j}(i\omega)$ as follows:

$$H_{\ddot{x},j}(i\omega) = 1 - \omega^2 H_{y,j}(i\omega) \tag{3.5}$$

$$H_{r,j}(i\omega) = H_{y,j}(i\omega) - H_{y,j-1}(i\omega) \quad (j \geqq 2), \qquad H_{r,1}(i\omega) = H_{y,1}(i\omega) \tag{3.6 a,b}$$

Figs.4 and 5 show the frequency response function of absolute acceleration of the superstructure calculated by Eqn.3.5 and that of relative story displacement of the isolation layer calculated by Eqn.3.6, respectively. These frequency functions are larger than base isolated building near 2[*Hz*] (as natural frequency of substructure). In particular, response amplification is very large at γ_1=1. In addition, as the mass ratio becomes large, the frequency response function becomes similar.

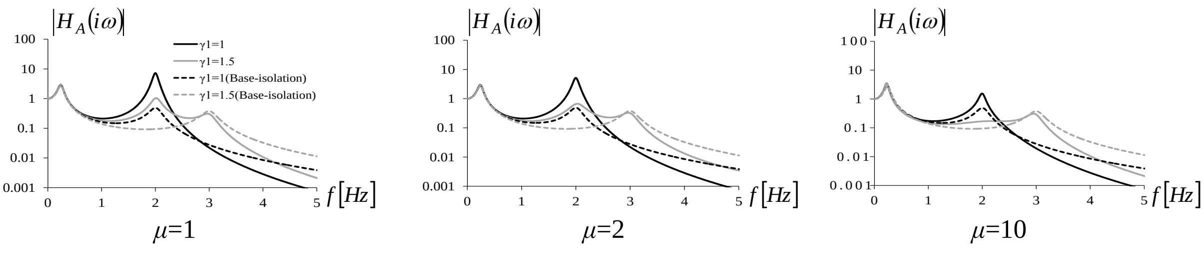

Figure 4. Frequency response function of absolute acceleration of the superstructure

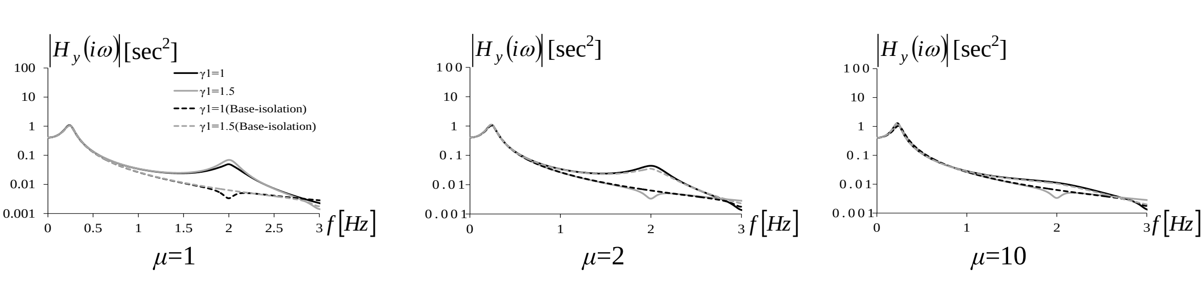

Figure 5. Frequency response function of relative story displacement of isolation layer

4 RANDOM VIBRATION RESPONSE

4.1 The Mean Square of the Response

The mean square of the response σ_m^2 to $S(\omega)$ (as power spectrum of ground motion) is calculated by using the frequency transfer function $H(i\omega)$ as in Eqn.4.1. In analytical studies, the power spectrum is assumed to be ideally white noise S_0 including all frequency ranges. Superstructure response ratio between SI-buildings with a vibration system above and below the isolation layer and base isolated buildings at the specific period ratio γ_1' is calculated from Eqn.4.2. Isolation layer response ratio between SI-buildings with vibration system above and below the isolation layer and the base isolated buildings is calculated from Eqn.4.3. Substructure response ratio between SI-buildings with vibration system above and below the isolation layer and base fixed buildings is calculated from Eqn.4.4. By normalizing the response, it is possible to calculate the response without depending on the frequency.

$$\sigma_m^2 = \int_{-\infty}^{\infty} \left|H(i\omega)\right|^2 S(\omega) d\omega, \qquad \sigma_m^2 = \int_{-\infty}^{\infty} \left|H(i\omega)\right|^2 S_0 d\omega \tag{4.1}$$

Response ratio:

$$\sigma_m / \sigma_{m,\gamma_1'} = \sqrt{\int_0^{\infty} \left|H_y(i\omega)\right|^2 d\omega \Big/ \int_0^{\infty} \left|H_{y,Base-isolation}(i\omega)\right|^2 d\omega} \tag{4.2}$$

$$\sigma_m / \sigma_{m,Base-isolation} = \sqrt{\int_0^{\infty} \left|H_y(i\omega)\right|^2 d\omega \Big/ \int_0^{\infty} \left|H_{y,Base-isolation}(i\omega)\right|^2 d\omega} \tag{4.3}$$

$$\sigma_m / \sigma_{m,Base-fixed} = \sqrt{\int_0^{\infty} \left|H_y(i\omega)\right|^2 d\omega \Big/ \int_0^{\infty} \left|H_{y,Base-fixed}(i\omega)\right|^2 d\omega} \tag{4.4}$$

where σ_m, $\sigma_{m,\gamma'}$, $_1\sigma_{m,Base\text{-}isolation}$ and $\sigma_{m,Base\text{-}fixed}$ are the root-mean-square(RMS) of the random response of SI-buildings with vibration system above and below the isolation layer, that of base isolated buildings at the specific period ratio, that of base isolated buildings and that of base fixed buildings, respectively. Fig.6 and 7 show the comparison of the response obtained from the Eqn.4.2, 4.3 and 4.4 and seismic response analysis. The RMS value ratio of the random response can be fitted to the response obtained from the seismic response analysis comparatively, therefore it is possible to evaluate the seismic response simply by using random vibration response.

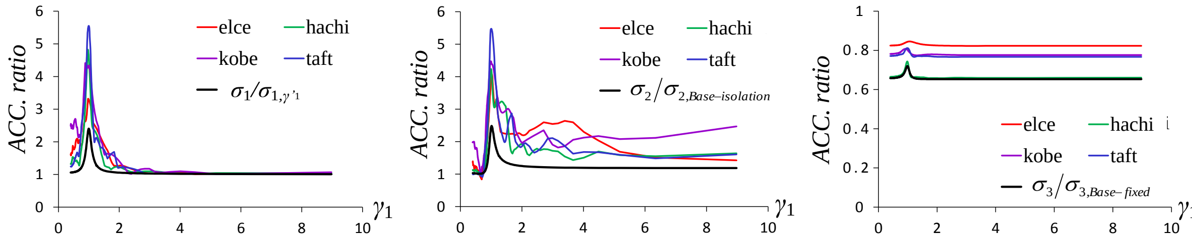

Figure 6. Comparison of the response (absolute acceleration of building top)

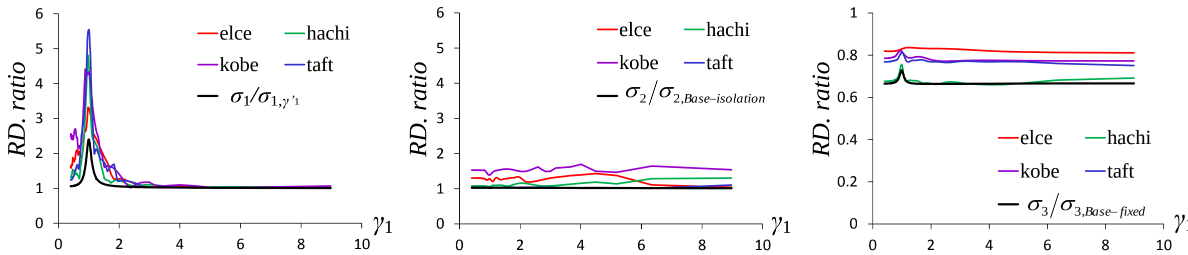

Figure 7. Comparison of the response (relative story displacement of isolation layer)

4.2 Buildings with the Vibration System on Either Superstructures or Substructures

As shown in Fig.8, SI-buildings with a vibration system above or below the isolation layer is expressed by using three mass model (e.g. seismically isolated buildings on the soft ground and the isolated high-rise buildings) and the formula for calculating the mean square value of the random response is proposed. In the case of the high-rise SI-building, it is assumed that h_3=0 and ω_3=∞. In the SI-buildings on the soft ground, it is assumed that h_1=0 and ω_1=∞.

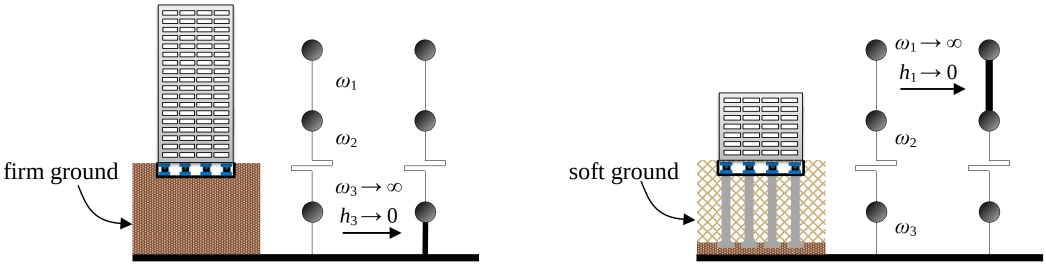

Figure 8. SI-buildings with vibration system above or below the isolation layer expressed by three mass model

Superstructure response ratio between high-rise SI-buildings and the SI-buildings at the specific period ratio γ_2' is calculated from Eqn.4.5 and 4.6. The substructure response ratio to base isolation buildings is calculated by Eqn.4.7 and 4.8. Superstructure response ratio between SI-buildings on the soft ground and SI-building is calculated by Eqn.4.9 and 4.10. Substructure response ratio between buildings on the soft ground and base fixed building is calculated by Eqn.4.11 and 4.12. Where σ_y and $\sigma_{\ddot{x}}$ are the RMS value ratio of the random vibration response of the relative story displacement and that of the absolute acceleration response, respectively. In addition, damping of superstructure is assumed to be 0 to calculate Eqns.4.9 to 4.12 simply as shown Eqns.4.16 to 4.18.

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},\gamma_2'} = \sqrt{\frac{2{\gamma_2}^2 + 8h_2^2 + 1}{2{\gamma_2'}^2 + 8h_2^2 + 1}} \tag{4.5}$$

$$\sigma_y / \sigma_{y,\gamma_2'} = \frac{{\gamma_2}^2}{{\gamma_2'}^2} \sqrt{\frac{2{\gamma_2}^2 + 8h_2^2 + 1}{2{\gamma_2'}^2 + 8h_2^2 + 1}} \tag{4.6}$$

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},Base\text{–}isolation} = \sqrt{\frac{8h_2^2 + 1}{4h_2^2 + 1}} \tag{4.7}$$

$$\sigma_y / \sigma_{y,Base\text{–}isolation} = \sqrt{\frac{1}{2}{\gamma_2}^2 + 1} \tag{4.8}$$

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},Base\text{–}isolation} = \sqrt{h_2\omega_1 \frac{\begin{bmatrix} h_1\omega_1\left\{\omega_1^2 + \omega_2^2\left(\mu_1+\mu_2\right)\right\} + h_2\omega_1\left\{\omega_1^2\left(\mu_1+\mu_2\right) + \omega_2^2\left(1+\mu_1+\mu_2\right)^2\right\} \\ +4\begin{Bmatrix} h_1^3\omega_1\omega_2^2 + h_1^2h_2\left(\omega_1^2\omega_2 + \omega_2^3\left[1+\mu_1+\mu_2\right]\right) \\ +h_1h_2^2\left(\omega_1^3 + \omega_1\omega_2^2\left[1+\mu_1+\mu_2\right]\right) + h_2^2\omega_1^2\omega\left(1+\mu_1+\mu_2\right) \end{Bmatrix} \\ +16h_1^2h_2^2\omega_1\omega_2\left(h_1\omega_2 + h_2\omega_1\right) \end{bmatrix}}{D_1'}} \tag{4.9}$$

$$\sigma_y / \sigma_{y,Base-isolation} = \omega_1\omega_2 \sqrt{h_2\omega_2 \frac{\begin{bmatrix} 2h_1\omega_1\left\{(\mu_1+\mu_2)+(\omega_1/\omega_2)^2\right\} \\ +2h_2\omega_2\left\{(1+\mu_1+\mu_2)^2+(1+\mu_1+\mu_2)(\omega_1/\omega_2)^2\right\} \\ +8h_1h_2\begin{Bmatrix} h_1\omega_2\left([1+\mu_1+\mu_2]+[\omega_1/\omega_2]^2\right) \\ +h_2\omega_1\left([1+\mu_1+\mu_2]+[h_1/h_2]^2\right)\end{Bmatrix}\end{bmatrix}}{D_2'}} \tag{4.10}$$

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},Base-fixed} = \sqrt{h_1 \frac{\begin{bmatrix} h_1\omega_1\omega_2^3(\mu_1+\mu_2)+h_2\left\{(\omega_1^2-\omega_2^2[1+\mu_1+\mu_2])^2\right\}+\omega_1^2\omega_2^2(\mu_1+\mu_2) \\ +4\begin{Bmatrix} h_1^3\omega_1\omega_2^3(\mu_1+\mu_2)+h_1^2h_2\left([\omega_1^2-\omega_2^2]^2+\omega_1^2\omega_2^2+\omega_2^2[\mu_1+\mu_2]\right) \\ +h_1h_2^2\left(\omega_1\omega_2^3[1+\mu_1+\mu_2]+\omega_1^3\omega_2\right)+h_2^2\omega_1^2\omega_2^2(1+\mu_1+\mu_2)\end{Bmatrix} \\ +16h_1^2h_2\omega_1\omega_2\left\{h_1h_2(\omega_1^2+\omega_2^2)+\omega_1\omega_2(h_1^2+h_2^2)\right\}\end{bmatrix}}{D_3'}} \tag{4.11}$$

$$\sigma_y / \sigma_{y,Base-fixed} = \omega_1 \sqrt{h_2\omega_1 \frac{\begin{bmatrix} 2h_1\omega_1\omega_2^2\left\{(\mu_1+\mu_2)^2+(\mu_1+\mu_2)(1+\mu_1+\mu_2)^2(\omega_2/\omega_1)^2\right\} \\ +2h_2\omega_1^2\omega_2\begin{Bmatrix}\left(1-[1+\mu_1+\mu_2]^2[\omega_2/\omega_1]^2\right) \\ +(\mu_1+\mu_2)(1+\mu_1+\mu_2)^2(\omega_2/\omega_1)^2\end{Bmatrix} \\ +8h_1h_2^2\omega_1\omega_2^2(1+\mu_1+\mu_2)^2\left\{1+(1+\mu_1+\mu_2)(\omega_2/\omega_1)^2\right\} \\ +8h_2^3\omega_2^3(1+\mu_1+\mu_2)^2\left\{(1+\mu_1+\mu_2)+(h_1/h_2)^2\right\}\end{bmatrix}}{D_2'}} \tag{4.12}$$

$$D_1' = (1+4h_2^2)\begin{bmatrix}(\mu_1+\mu_2)\omega_1\omega_2(h_1\omega_2+h_2\omega_1)^2+h_1h_2\left\{\omega_1^2-\omega_2^2(1+\mu_1+\mu_2)\right\}^2 \\ +4h_1h_2\omega_1\omega_2\left\{\omega_1\omega_2\left(h_1^2+h_2^2[1+\mu_1+\mu_2]\right)+h_1h_2\left\{\omega_1^2+\omega_2^2[1+\mu_1+\mu_2]\right\}\right\}\end{bmatrix} \tag{4.13}$$

$$D_2' = 2\omega_1\omega_2\begin{bmatrix}(\mu_1+\mu_2)\omega_1\omega_2(h_1\omega_2+h_2\omega_1)^2+h_1h_2\left\{\omega_1^2-\omega_2^2(1+\mu_1+\mu_2)\right\}^2 \\ +4h_1h_2\omega_1\omega_2\left\{\omega_1\omega_2\left(h_1^2+h_2^2[1+\mu_1+\mu_2]\right)+h_1h_2\left\{\omega_1^2+\omega_2^2[1+\mu_1+\mu_2]\right\}\right\}\end{bmatrix} \tag{4.14}$$

$$D_3' = (1+4h_1^2)\begin{bmatrix}(\mu_1+\mu_2)\omega_1\omega_2(h_1\omega_2+h_2\omega_1)^2+h_1h_2\left\{\omega_1^2-\omega_2^2(1+\mu_1+\mu_2)\right\}^2 \\ +4h_1h_2\omega_1\omega_2\left\{\omega_1\omega_2\left(h_1^2+h_2^2[1+\mu_1+\mu_2]\right)+h_1h_2\left\{\omega_1^2+\omega_2^2[1+\mu_1+\mu_2]\right\}\right\}\end{bmatrix} \tag{4.15}$$

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},Base-isolation} = \sqrt{\frac{({\gamma_3}^2+4h_2^2)(1+\mu_1+\mu_2)+(\mu_1+\mu_2)}{(\mu_1+\mu_2)(1+4h_2^2)}} \tag{4.16}$$

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},Base-fixed} = \sqrt{\frac{(1+\mu_1+\mu_2)^2{\gamma_3}^2+(1+\mu_1+\mu_2)}{(\mu_1+\mu_2)}} \tag{4.17}$$

$$\sigma_{\ddot{x}} / \sigma_{\ddot{x},Base-isolation} = \sigma_{\ddot{x}} / \sigma_{\ddot{x},Base-fixed} = 0 \tag{4.18}$$

Fig.9 shows the RMS value ratio of the random vibration response of the superstructure calculated by Eqns.4.4 and 4.5. The response amplification of the relative story displacement and absolute acceleration of the superstructure becomes small with increasing the period of the isolation layer T_d. The response reduction of absolute acceleration of superstructure is greater with increasing the period of the superstructure *Tu*. However, the period ratio γ_2 gives little effect to the response. Fig. 10 shows the RMS value ratio of the random vibration response of isolation layer calculated by Eqns. 4.8 and 4.9. The period of ground and γ_2 gives little effect to the response of the isolation layer. Fig.11 shows the result of the RMS value ratio of the random vibration response calculated by Eqns.4.15 and 4.17. The response amplification of the relative story displacement and absolute acceleration of the superstructure becomes small with increasing the period of the isolation layer T_d and the response reduction is greater with increasing the ground period. The response can be suppressed with decreasing the mass ratio.

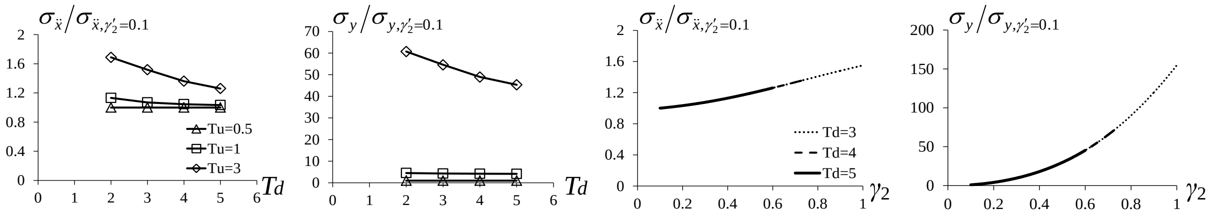

Figure 9. RMS value ratio of superstructure response of high-rise buildings

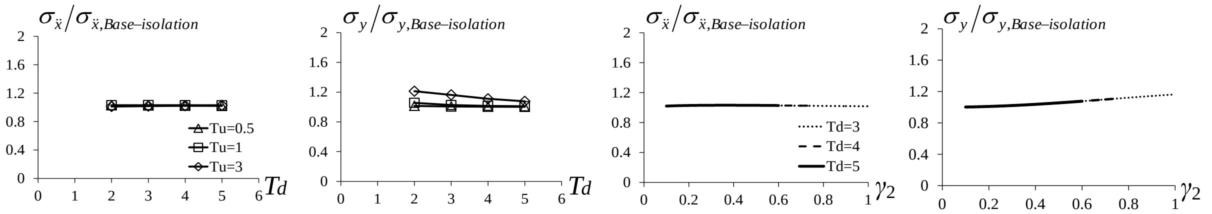

Figure 10. RMS value ratio of isolation layer response of high-rise Buildings

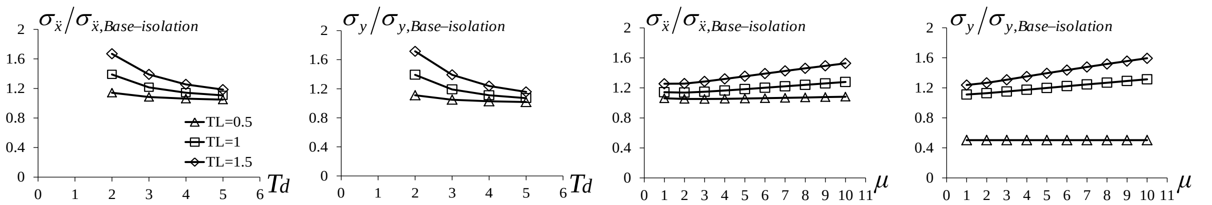

Figure 11. RMS value ratio of superstructure response of buildings on the soft ground

4.3 Buildings with the Vibration System to both Superstructures and Substructures

Figs.12 to 14 show the RMS value ratio of the acceleration response of SI-buildings with a vibration system above and below the isolation layer (e.g. high-rise SI-buildings on the soft ground and the mid-story isolated buildings). The absolute acceleration response of the isolation layer and the superstructure is amplified greatly at $\omega_{FF}/\omega_F=\omega_\ell/\omega_F$, the mode coupling effect is confirmed. Though the substructure response is decreased compared to the response of only the substructure, the response is reduced by the modal coupling effect. As the mass value ratio μ is large, the response amplification is greater. When the damping ratio of the isolation layer h_2 is large, the amplification is smaller. Figs.15 to 17 show the RMS ratio of the relative story displacement and acceleration response of SI-buildings with the vibration system above and below the isolation layer. The absolute acceleration superstructure response is amplified greatly by the modal coupling effect, the response of the isolation layer is not affected by it.

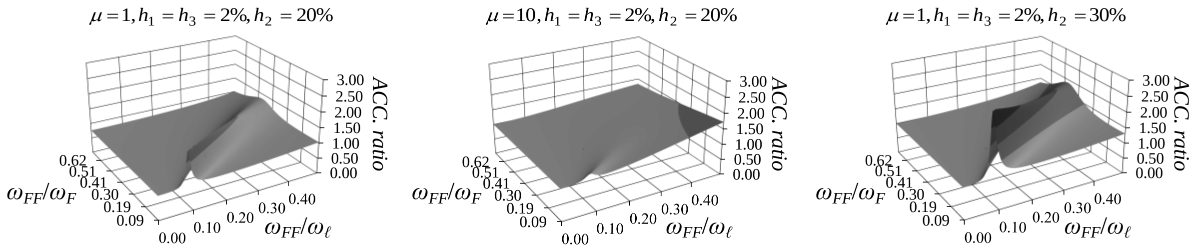

Figure 12. RMS value ratio of acceleration response of superstructure

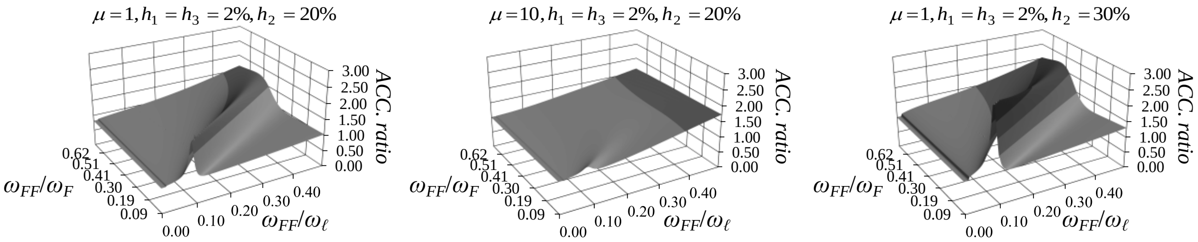

Figure 13. RMS value ratio of acceleration response of isolation story

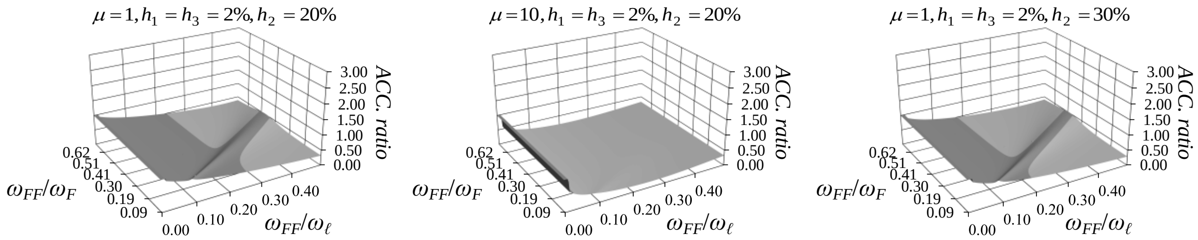

Figure 14. RMS value ratio of acceleration response of substructure

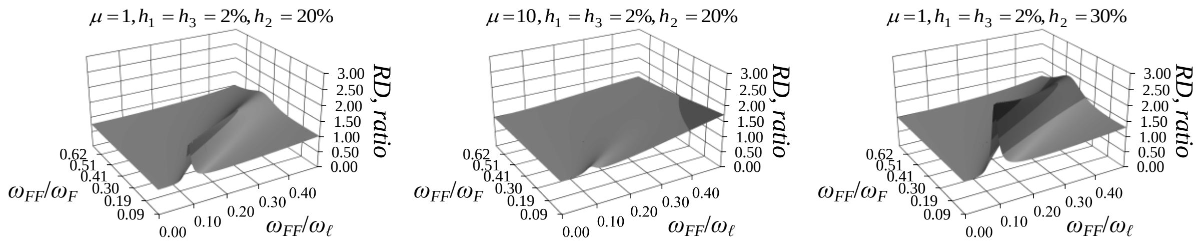

Figure 15. RMS value ratio of relative story displacement of superstructure

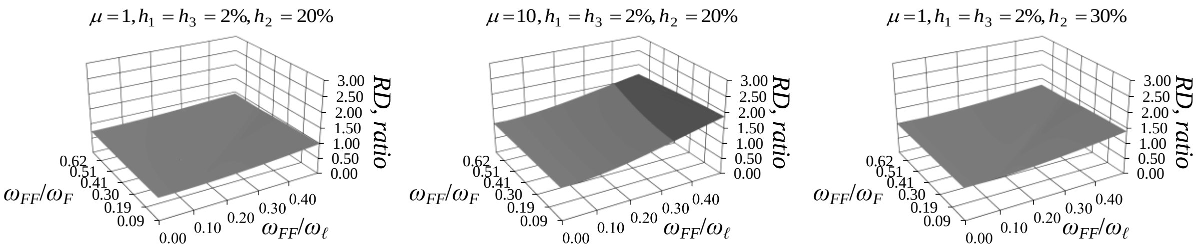

Figure 16. RMS value ratio of relative story displacement of isolation story

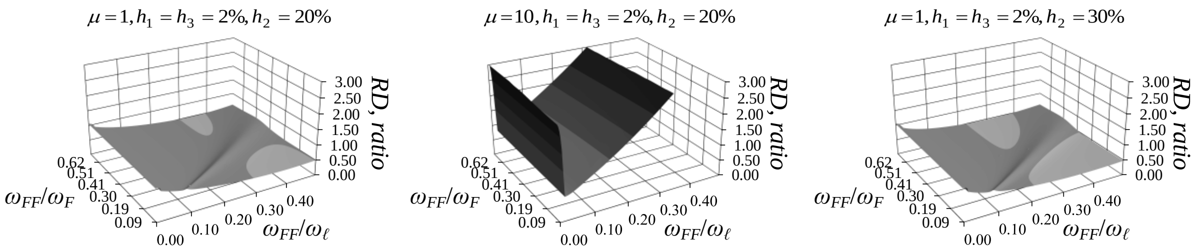

Figure 17. RMS value ratio of relative story displacement of substructure

5. COMCLUSION

This paper describes vibration characteristics of the building with vibration system above and below the isolation story calculated by the random response and eigenvalue analysis.

By parametric analysis of random response, the structural condition affecting the response is shown theoretically. The following was found; SI-buildings with a vibration system above or below the isolation layer do not depend on the period ratio γ_2. In the SI-buildings with a vibration system above or below the isolation layer, the effect to the response from mass ratio μ is large and as the damping ratio of isolation story is large, the response amplification by modal coupling effect is greater.

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